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XIV.

CLASSIFICATION OF THE ATOMIC WEIGHTS IN TWO ASCENDING SERIES, CORRESPONDING TO THE GROUPS OF ARTIADS AND PERISSADS.

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Presented by the Corresponding Secretary, April 10, 1889.

If the atomic weights of all chemical elements are arranged in a single ascending series, it will take the following form if expressed in whole numbers:

1, — 7, 9, 11, 12, 14, 16, 19, — 23, 24, 27, 28, 31, 32, 35, — 39,
40, 44, 48, 51, 52, 55, 56, 59, etc.;

corresponding to the elements,

H, — Li, Be, B, C, N, O, F, — Na, Mg, Al, Si, P, S, Cl, — K,
Ca, Sc, Ti, V, Cr, Mn, Fe, Co, etc.

The well known " Law of Octaves " calls attention to the fact that each element bears a strong resemblance to that seven places from it in this series, and the " Periodic Law " states that the properties of elements stand in periodic relation to their atomic weights. These laws have been enunciated and illustrated by Newlands, Mendeléeff, Lothar Meyer, and others, and are now familiar to all students of chemistry.

Referring to these laws, Wurtz in his "Atomic Theory " says: " Though it may be generally true that the properties of bodies are subject to periodic modifications with the increase of their atomic weights, the law of these modifications escapes our observation, and seems to be of a complicated nature; for, on the one hand, the atomic weights of successive elements vary within considerable limits without displaying any regularity in these variations; on the other hand, we must confess that the gradations of properties, in other words the greater or less divergencies between properties of successive elements, do not appear to depend upon the degree of the differences between the atomic weights. These are real difficulties." *

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* The Atomic Theory, 1881, p. 162.

Lothar Meyer on the same general subject says, "There can be no doubt as to the fact that these differences are subject to law";[*] and, "There is still much work for the hands and mind; but it will be thoroughly rewarded. The prize is a systematic inorganic chemistry which will bear comparison with the thoroughly developed system of organic chemistry."[†]

The object of this paper is to contribute to the removal of these difficulties, by showing that the increase in the atomic weights of the elements follows a law of the utmost simplicity in its general form, and identical with that of the series of organic compounds.

Let us take the series above mentioned and consider whether any of its terms can be classed in a series of constant increase. Beginning with 2 as a modulus, we find that it applies to 7, 9, and 11, with no recurrence of this difference except for the terms 12, 14, 16; 3 applies only to 9, 12, — 24, 27, — 48, 51, and to 16, 19 * * 28, 31 * * * * * 52, 55; 4 however applies to 7, 11 * 19, 23, 27, 31, 35, 39 * * 51, 55, 59, and to 12, 16 * 24, 28, 32 * 40, 44, 48, 52, 56; thus embracing in two parallel series all the terms of the first three periods of Newlands and Mendeléeff, with the exception of 9 and 14, i. e. 22 out of 24. The probability that these numbers would so far coincide with the regular series from the result of chance, is too slight to be entertained. If now, in addition to this coincidence, any points of resemblance can be discovered among several of the elements in each series, such resemblances are significant; but when it appears that all or nearly all in each series fall into a distinct group that has already been recognized as such by chemists, there is scarcely room for doubt that the regularity of the series is connected with the intrinsic nature of the elements.

Those of the first series are all PERISSADS and those of the second ARTIADS, or elements of uneven and even quantivalence respectively, with the single exception in one case of scandium, a newly discovered element whose atomic weight has never been so accurately determined as to throw it out of its group, and cobalt and nickel, which apparently belong to another group. For the present, therefore, the law of regular increase in the atomic weight of the parallel series is spoken of as the Law of Artiad and Perissad Increase, or more briefly as the PERISSAD LAW.

By similar methods, we find that the numbers between 70 and 100 fall naturally into two series, with the common difference of 5 for the perissads and perhaps 4 for the artiads. The latter series, however, is somewhat indefinite.

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[*] Modern Theories of Chemistry, English Translation, 1888, p. 160.

[†] Ibid., p. 170.

Between 100 and 150 the perissads increase regularly, with a common difference of about $6\frac{1}{4}$, and the artiads less regularly, with the same difference, as shown in Tables I. and II.

Too little is known of the atomic weights between 150 and 190, and of those above 210, to justify their classification. Between 190 and 210, we find that 4 applies to 195, 199 * 207, and to 196, 200, 204, 208.

All of the first series are artiads, and in the second all except 200, or Hg, are recognized as perissads, and this element is so similar in many respects to Cu, Ag, and Au that for the present it is allowed to remain in its place. There only remain unclassified 9, 14, 59, 104, and 193. Of these numbers, 9 is the atomic weight of Be and appears to differ too much from 8, the serial number of this element, to be recognized in its natural place.

The remaining numbers, 14, 59, 104 * 193, form a series by themselves, with a difference of a little less than 45. Ni and Co correspond to 59, Ru and Rh to 104, and Ir to 193. These elements are always classified together, and this regularity of increase has often been noticed. But perhaps 14, or N, falls into this series accidentally.

In Tables I. and II. the first column shows the symbols for the elements; the second column, the serial numbers derived from the formula; the third column, the observed atomic weights; and the fourth column, the deviations from the serial numbers. The next columns show the specific gravity, the atomic volume, the fusibility, malleability, and place in an electro-chemical series for each element, and the last column the group in the classification of Newlands and Mendeléeff to which the element has been assigned. The horizontal lines divide the series and periods of this system.

The observed atomic weights are taken from the lists of Clarke,* L. Meyer,† and Van der Plaats,‡ and in most cases by selecting for each element that one of the values that differs least from the mean, taking oxygen at 16 for a standard, and expressing but one place of decimal fractions. The data for the next four columns are taken from Meyer's "Modern Theories." To express their fusibility, the elements are divided into seven classes, that represented by 1 being the most fusible. The brittle and malleable elements are distinguished by the initial letters B and M. In the electro-chemical series taken from Barker's "Text-Book of Chemistry,"* 1 is the most electro-positive in an acid solution, and 63 the most negative.

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* The Constants of Nature. A Recalculation of Atomic Weights, 1882.

† Modern Theories of Chemistry, English Translation, 1888.

‡ Verification of the Atomic Weights of M. Stas.

It appears from these tables that none of the deviations from the serial numbers exceed 0.6 excepting that for Cb among the perissads, and Zn and Mo among the artiads; Zn differs by just a unit, and seems to form an exception to the regularity.

In his account of the Discovery of the Periodic Law,† Newlands points out the irregularity of the single series, illustrating it by several tables, and the data are clearly set forth and tabulated in a recent paper by Venable, on the Recalculation of the Atomic Weights.‡

In the artiad grand group no atomic weight corresponds to 20, 36, 83, or 131, and a reference to the electro-chemical series will show that these are the points at which the elements change from a negative to a positive maximum, corresponding also to the maximum atomic volumes, and to the end of the Mendeléeff periods.

These points are marked with asterisks in the table.

Analogy points to the possibility of elements with atomic weights of 15, 43 or 44, 47, 60, and perhaps of 99, 100, and 143.5.

The newly discovered philippium and praseodymium may perhaps correspond to 47 and 143.5, respectively, but there appears to be no place in either series for neodymium or 140.3.

In each of the grand groups, perissads and artiads, the breaks between the minor groups of common difference occur at or near the minimum points of the series of atomic volumes, and therefore midway between the dividing lines above mentioned.

The first term of each of the groups of common difference, except the first, viz. Ga, Ag, Au, Ge, Pd, and Pt, appears to be a heavy malleable metal, electrically neutral, and with an atomic volume a little above 9 in the artiad, and 10 in the perissad groups.

With the increase of atomic volume is generally associated an increase in electro-negative properties, and, as a rule, the elements become fusible, brittle, and diamagnetic.

With the maximum atomic volume, the elements change from the extreme of negative to positive, from diamagnetic to magnetic, from brittle to malleable; and with the decrease of volume, they lose their electro-positive properties, and, as a rule, become at last brittle and infusible.

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* Text-Book of Chemistry, p. 16.

† The Periodic Law, p. 27.

‡ Journal of Analytical Chemistry, January, 1889, p. 48.

TABLE I. — PERISSADS.

El.	Atomic Weights.			Physical Properties.					Gr.
	Ser.	Obs.	Dev.	Sp. Gr.	At. Vol.	Fus.	Mal.	Elec.	
H	1	1.0	0.0	....	....	..	..	..	I
	$+ 6 + n \times 4$								
Li	7	7.0	0.0	0.59	11.9	1	M	5	I
B	11	11.0	0.0	2.68	4.0	6	B	49	III
	15	?							
F	19	19.0	0.0	....	....	1	B	60	VII
Na	23	23.1	+0.1	0.97	23.7	1	M	4	I
Al	27	27.1	+0.1	2.56	10.6	3	M	13	III
P	31	31.0	0.0	2.30	13.5	2	B	55	V
Cl	35	35.5	+0.5	1.38	25.6	1	B	59	VII
K	39	39.1	+0.1	0.86	45.4	1	M	3	I
Sc	43	44.?	....	....	....	..	..	..	III
	47	?							
V	51	51.3	+0.3	5.50	9.3	7	B	52	V
Mn	55	55.0	0.0	8.00	6.9	5	B	19	VII
Co ?	59	(59.0	0.0	8.50	6.9	5	M	23)	
Cu	63	63.5	+0.5	8.80	7.2	3	M	31	I
	$+ 7 + n \times 5$								
Ga	70.0	70.0	0.0	5.96	11.7	1	?	?	III
As	75.0	75.0	0.0	5.67	13.2	2	B	54	V
Br	80.0	80.0	0.0	2.97	26.9	1	B	58	VII
Rb	85.0	85.4	+0.4	1.52	56.1	1	M	2	I
Y	90.0	89.8	—0.2	....	....	..	..	11	III
Cb	95.0	94.2	—0.8	6.27	15.0	7	B	44	V
	100.0								
	$+ 7.5 + n \times 6.25$								
Ag	107.5	107.9	+0.4	10.50	10.2	3	M	32	I
In	113.7	113.7	0.0	7.43	15.3	1	M	27	III
Sb	120.0	120.1	+0.1	6.70	17.9	2	B	47	V
I	126.3	126.8	+0.5	4.94	25.6	1	B	57	VII
Cs	132.5	132.9	+0.3	1.88	70.6	1	M	1	I
La	138.8	138.8	0.0	6.20	22.3	3 ?	..	18	III
Di	145.0	145.0	0.0	6.50	22.3	3 ?	..	17	V
	$? + n \times 4$								
Au	196.0	196.6	+0.6	19.30	10.2	3	M	40	I
Hg	200.0	200.2	+0.2	13.59	14.7	1	M	33	II
Tl	204.0	204.2	+0.2	11.86	18.1	2	M	24	III
Bi	208.0	208.0	0.0	9.82	21.1	2	B	29	V

TABLE II. — ARTIADS.

El.	Atomic Weights.			Physical Properties.					Gr.
	Ser.	Obs.	Dev.	Sp. Gr.	At. Vol.	Fus.	Mal.	Elec.	
	$12 + n \times 4$								
		?							
C	12.0	12.0	0.0	0.33	3.6	7	B	54	IV
O	16.0	16.0	0.0	....	....	1	B	63	VI
	20.0	*							
Mg	24.0	24.0	0.0	1.74	13.8	3	M	9	II
Si	28.0	28.1	+0.1	2.49	11.2	6	B	42	IV
S	32.0	32.1	+0.1	2.04	15.7	1	B	62	VI
	36.0	*							
Ca	40.0	40.0	0.0	1.57	25.4	2	M	8	II
	44.0	?							
Ti	48.0	48.1	+0.1	....	....	..	B	43	IV
Cr	52.0	52.3	+0.3	6.80	7.7	5	B	53	VI
Fe	56.0	56.0	0.0	7.80	7.2	5	M	21	VIII
	60.0	?							
Zn	64.0	65.0	+1.0	7.15	9.1	2	M	20	II
	$+ 7 + n \times 4$								
Ge	71.0	?	....	?	....	?	..	?	IV
As	75.0	75.0	0.0	5.67	13.2	2	B	54	V
Se	79.0	79.0	+0.0	4 60	17.1	1	B	56	VI
	83.0	*							
Sr	87.0	87.5	+0.5	2.50	34.9	2	M	7	II
Zr	91.0	90 6	—0.4	4.15	21.7	6	B	14	IV
Mo	95.0	95.9	+0.9	8.60	11.1	6	B	51	VI
	99.0	?							
	$+ 7 + n \times 6.25$								
Pd	106.0	106.0	0.0	11.50	9.2	4	M	34	VIII
Cd	112.2	112.2	0.0	8.65	12.9	2	M	25	II
Sn	118.5	118.0	+0.5	7.29	16.1	2	M	28	IV
Te	124.8	125.0	—0.2	6.25	20.2	2	B	46	VI
	131.0	*							
Ba	137.2	137.1	—0.1	3.75	36.5	2	M	6	II
Ce ?	143.5	?	?	6.70	21.0	3 ?	..	16	IV
	$? + n \times 4$								
Pt	195.0	194.9	—0.1	21.50	9.1	5	M	37	VIII
Os	199.0	198.9	—0.1	22.50	8.7	5	B	39	VIII
	203.0	?							
Pb	207.0	206.9	—0.1	11.38	18.1	2	M	26	IV
	$14 + n \times 44.8$								
Ni	58.8	58.7	—0.1	8.80	6.7	4	M	22	VIII
Co	58.8	59.0	+0.2	8.50	6.9	5	M	23	VIII
Ru	103.6	104.0	+0.4	12.26	8.4	5	B	35	VIII
Rh	103.6	104.2	+0.6	12.10	8.6	5	M	36	VIII
	148.4	?							
Ir	193.2	193.0	—0.2	22.46	8.6	5	B	38	VIII

The study of the periodic law has directed attention to the relations between the atomic weights and these properties, many of which were previously treated as functions of the electro-chemical order.

When the exact atomic weights are all determined with sufficient accuracy, it is natural to infer that the deviations from the regular increase will show a law as significant as the approximate coincidence with the serial numbers, and even now we see clear evidences of this law. To make it more apparent, it will first be necessary so to adjust the formula as to reduce these differences to a minimum, and in the low atomic weights to take account of smaller fractions.

The formula $a + n d$ then has the following values for the several groups of common difference: —

$$\begin{array}{rr}
6.99 + n \times 4.02 & 12.00 + n \times 4.01 \\
70.25 + n \times 4.85 & 74.88 + n \times 4.12 \\
107.85 + n \times 6.20 & 105.98 + n \times 6.22
\end{array}$$

Table III. shows the deviations, arranged in the groups and series of the periodic law; the lower division shows the electro-chemical numbers in the same form.

Neglecting insignificant deviations, we find the positive results, or those where the atomic weight is slightly in excess of the serial number, either near the extremes of the electric series, in elements of maximum atomic volume, etc., or in the very centre of this series. The negative results occur half-way between the centre and the extremes. Of the perissads, 1, 2, — 31, 32, — 57, 59, are positive, and 17, 18, 19, 21, — 44, 47, 54, 55, are negative; of the artiads, 7, — 46, 51, 53, are positive, and 8, 14, 21, 23, 28, are negative.

In the periodic arrangement, the first and second groups show positive deviations in the high series of this arrangement; the third, fourth, and fifth, negative in the high series; the sixth, positive in the high series; and the seventh, positive in two terms, and insignificant in two. The seventh and eighth groups are negative in the third series. The deviation of Zn is not included in these calculations, nor is the cause of its deviation yet apparent. Perhaps the perissads of the second group are formed from an artiad nucleus, and the artiads of the second group from a perissad nucleus, thus: * 65, 70, 75, 80, etc., and 63 * 71, 75, 79, etc. The last line shows the algebraic mean of the deviations in each group, which, as might be expected, corresponds nearly to the relative atomic volumes.

To do justice to the bearing of these results on the physical question of the ultimate nature of "atoms" would involve a mathematical

TABLE III. — DEVIATIONS.

Gr.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Ser.								
1	—.03	?	—.03	.00	?	—.01	—.03	
2	—.02	—.02	.00	+.02	—.08	+.01	+.32	
3	—.02	—.08	?	.00	+.05	+.19	(—.26)	—.11
4	+.06	?	—.30	?	—.06	+.03	+.01	
5	+.64	+.28	+.01	—.80	—.30	+.47		+.02
6	+.08	+.03	—.36	—.42	—.14	+.31	+.41	
7	+.25	+.02	—.18	?	—.05			
	+.14	+.05	—.14	—.25	—.09	+.17	+.18	—.05
ELECTRO-CHEMICAL ORDER.								
1	5	?	49	48	?	63	60	
2	4	9	13	42	55	62	59	
3	3	8	?	43	52	53	(19)	21
4	31	20	?	?	54	56	58	
5	2	7	11	14	44	51		34
6	32	24	27	28	47	46	57	
7	1	6	18	16	17			

discussion too prolonged for this paper; but the subject cannot be completed without a brief statement of its relation to well known systems and theories of Chemistry. A few extracts will serve as a basis to show what the perissad law is intended to contribute to the solution of the all-important problem.

In 1854, in a paper read before the American Academy on "The Numerical Relation between the Atomic Weights," Professor Cooke announced the character of the problem as follows: —

"Numerical relations between the atomic weights of the chemical elements have been very frequently noticed by chemists. One of the fullest expositions of these relations was that given by M. Dumas, of Paris, before the British Association for the Advancement of Science, at the meeting of 1851. This distinguished chemist at that time pointed out the fact, that many of the elements might be grouped in triads, in which the atomic weight of one was the arithmetical mean of those of the other two. Thus the atomic weight of Bromine is the mean between those of Chlorine and Iodine; that of Selenium is the mean between those of Sulphur and Tellurium; and that of Sodium, the mean between those of Lithium and Potassium.

"M. Dumas also spoke of the remarkable analogies between the properties of the members of these triads, comparing them with similar analogies observed in Organic Chemistry, and drew, as is well known, from these facts arguments to support the hypothesis of the compound nature of many of the now received elements. Similar views to those of Dumas have been advanced by other chemists.

"The doctrine of triads is, however, as I hope to be able to show in the present memoir, a partial view of this subject, since these triads are only parts of series similar in all respects to the series of homologues of Organic Chemistry, in which the differences between the atomic weights of the members is a multiple of some whole number. All the elements may be classified into six series, in each of which this number is different, and may be said to characterize its series. In the first it is 9, in the second 8, in the third 6, in the fourth 5, in the fifth 4, and in the last 3." (See Table IV.)

The paper speaks of the properties of the elements which are functions of the atomic weights, and says that it does not seem bold theorizing to suppose that the atoms of the members of the same series are formed of a common nucleus, to which has been added one or more groups of atoms, or perhaps one or more single atoms, to which the corresponding element has not been discovered.

Referring to this subject in 1857,* M. Dumas said: "I have often tried, as Mr. Josiah Cooke has on his part, to compare them, to combine them, and to discuss them, with the hope of drawing some conclusion from them with certainty, but I have been unable to draw from them anything but doubt. The formula deduced from the above simple progression" $(a + n\,d)$ "would not account for the generation of simple bodies, as Cooke had supposed, but organic radicles are not always formed by addition, they are also produced by substitution, as we see in the compound ammoniums." Dumas proposed to substitute a formula like $n\,a + n'\,d + n''\,d'$; a being the nucleus; d and d', the common differences; and n, n', n'', whole numbers. Table IV. shows the series of Cooke and Dumas.

Following in their footsteps, Professor Newlands extended their principles to include newly discovered elements. Employing Cannizzaro's atomic weights instead of those of the old system, and collating his own results and all discovered up to 1864, he arranged the groups in horizontal lines instead of vertical columns, and then discovered the "Law of Octaves," as shown in Table IV. The coincidence of the ordinal numbers led him, in 1865, to express the following opinion: "I will

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* Comptes Rendus, 1857, p. 709.

TABLE IV.

Cooke, 1854.

Ser.	III.		IV.	V.	VI.	VIII.	IX.	IV.
Gr.	3.	2. 1.	3, 2. 1.					2. 1. 3.
	H Li Na K Ag	Ca Mg Sr Zn Ba Cd Pb	Al Ti Cr Pd Mn Sn Fe Pt Co Ir Ni Os U Au Cu Hg	C B Si	O N P As Sb Bi	O S Se Mo Te V W Ta	O F Cy Cl Br I	Al Ti Cu Cr Pd Hg Mn Sn Fe Pt Co Ir Ni Os U Au
	Cu Mn			Ti	Cr V	As Mn	Cr Mn Os Au	

Dumas, 1857.

Form.	$7 + n.8$	$12 + n8$	$25 + n34$	$6 + n5$	$14 + n17$	$8 + n8$	$19 + n\,16.5 + n'28$	
	L Na K	Mg Ca Sr Ba Pb	Ti Sn Ta	C B Si Zr	N P As Sb Bi	Cr O Mo S V Se W Te	F Cl Br I	

Mendeléeff, 1869.

Gr.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Ser.								
1	H							
2	Li	Be	B	C	N	O	F	
3	Na	Mg	Al	Si	P	S	Cl	
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe Co Ni Cu
5	(Cu)	Zn	Ga	—	As	Se	Br	
6	Rb	Sr	?Y	Zr	Nb	Mo	—	Ru Rh Pd Ag
7	(Ag)	Cd	In	Sn	Sb	Te	I	
8	Cs	Ba	?Di	?Ce				
9	(—)							
10			?Er	?La	Ta	W		Os Ir Pt Au
11	(Au)	Hg	Ti	Pb	Bi			
12				Th		U		

TABLE IV. — *Continued.*

NEWLANDS, 1865.

	No.		No.		No.		No.		No.		No.		No.		No.
H	1	F	8	Cl	15	Co & Ni	22	Br	29	Pd	36	I	42	Pt & Ir	50
Li	2	Na	9	K	16	Cu	23	Rb	30	Ag	37	Cs	44	Tl	53
G	3	Mg	10	Ca	17	Zn	25	Sr	31	Cd	38	Ba & V	45	Pb	54
Bo	4	Al	11	Cr	19	Y	24	Ce & La	33	U	40	Ta	46	Th	56
C	5	Si	12	Ti	18	In	26	Zr	32	Sn	39	W	47	Hg	52
N	6	P	13	Mn	20	As	27	Di & Mo	34	Sb	41	Nb	48	Bi	55
O	7	S	14	Fe	21	Se	28	Ro & Ru	35	Te	43	Au	49	Os	51

endeavor to show that all the numerical relations among the equivalents pointed out by M. Dumas and others, including the well known triads, are merely arithmetical results flowing from the existence of the 'law of octaves,' taken in connection with the fact of the equivalents forming a series of numbers approaching to the natural order." And in 1866: "The fact that such a simple relation exists now, affords a strong presumptive proof that it will always continue to exist, even should hundreds of new elements be discovered. For, although the difference in the numbers of analogous elements might, in that case, be altered from 7, or a multiple of 7, to 8, 9, 10, 20, or any conceivable figure, the existence of a simple relation among the number of analogous elements would be none the less evident." * The law of regular increase, however, points to a relationship far more significant than the identity of their ordinal numbers.

Working independently of Newlands, Mendeléeff discovered the periodic law in 1869. It has offered a grand incentive to new discoveries and received well merited recognition throughout the world. The extracts from Wurtz and Meyer, at the beginning of this paper, show what it left to be desired.

A paper by Rev. Dr. Haughton, and an abstract of one by Mr. Stoney, have recently appeared in "The Chemical News." Each gives a clear enunciation of the nature of the problem. Dr. Haughton discovers some of the regular intervals noticed here. Unfortunately, the paper of Stoney, on "The Logarithmic Law of Atomic Weights" † is so abridged, that it is hard to determine how his results may compare with those herein discussed. The abstract states, that, in plotting the atomic volumes as ordinates of a diagram, the effort to extract information from the resulting curves was a failure; in plotting their cube roots, however, he found a logarithmic curve with perturbations which showed a distinct law of increase for perissads and artiads. The abstract was not discovered until most of this paper was written, and, from its indefinite statements, it would require much time to construct the curves and divine the inferences.

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* The Periodic Law, p. 20.

† The Chemical News, vol. lvii. p. 163.

At the close of his paper of 1854, Professor Cooke said: "To my conceptions Chemistry will then have become a perfect science, when all substances have been classed in series of homologues, and when we can make a table which shall contain, not only every known substance, but also every possible one, and when by means of a few general formulæ we shall be able to express all the properties of matter, so that, when the series of a substance and its place in the series are given, we shall be able to calculate, nay predict, its properties with absolute certainty. . . . Then the dreams of the ancient alchemist will be realized, for the problem of the transmutation of metals will have been theoretically, if not practically, solved."